TR-01-270

WADC TECHNICAL REPORT 58-309
ASTIA DOCUMENT NO. AD 209380

LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON NET SEAT

ONE OF A SERIES OF STUDIES PERTAINING TO CREW COMPARTMENT HABITABILITY FOR EXTENDED MISSIONS

JESS FORREST
EDWARD A. WADE
WITH THE STAFF ASSISTANCE OF
W. K. CARTER
R. F. SLECHTA

BIO-MECHANICS LABORATORY
DEPARTMENT OF SOCIOLOGY
TUFTS UNIVERSITY

DECEMBER 1958

CONTRACT NO. AF 33(616)-3068

AERO MEDICAL LABORATORY
WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NOTICES

AD-209380

WADC TECHNICAL REPORT 58-309
ASTIA DOCUMENT NO. AD 209380

LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON NET SEAT

ONE OF A SERIES OF STUDIES PERTAINING TO CREW COMPARTMENT HABITABILITY FOR EXTENDED MISSIONS

JESS FORREST
EDWARD A. WADE
WITH THE STAFF ASSISTANCE OF
W. K. CARTER
R. F. SLECHTA

BIO-MECHANICS LABORATORY
DEPARTMENT OF SOCIOLOGY
TUFTS UNIVERSITY

DECEMBER 1958

CONTRACT NO. AF 33(616)-3068
PROJECT NO. 7222
TASK NO. 71747

AERO MEDICAL LABORATORY
WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

McGregor & Werner Midwest Corp., Dayton, O.
25-535 & 536-1100-3-27-59

FOREWORD

The design research program described in this report was carried out at the Bio-Mechanics Laboratory, Tufts University, Medford 55, Massachusetts. It is one of a series of studies on light-weight seating being conducted as part of the work under Contract AF 33(616)-3068, Project No. 7222, "Biophysics of Space Flight;" Task No. 71747 "Design Criteria of Crew Stations for Space Flight."

Mr. Charles A. Dempsey, Biophysics Branch, Aero Medical Laboratory, was the Project Engineer and Mr. W. K. Carter was the contractor's Project Director.

The design research activity was planned and carried out by Mr. Jess Forrest, Industrial Designer. Dr. Edward A. Wade assisted in writing and preparation of the final report.

The authors are indebted to several individuals for their contributions. Among those who assisted in this task were Mr. W. K. Carter, Dr. E. M. Bennett, Mr. John Duddy, and Miss Sheila Gallivan.

We should also like to thank Miss Frances E. Leighton for organizing the material. Mr. LeRoy Christie deserves special mention for the preparation of graphs and figures.

In addition, we feel indebted to the subjects. Their cooperation and earnest attitudes were of primary importance. Many of them were members of the Tufts University AFROTC. Col. Herman Hauck, USAF, Commanding Officer of the unit, and members of his staff aided in interesting subjects in participating and were helpful to the program on other occasions.

ABSTRACT

This report describes a design research program for a light-weight aircraft seat made from nylon netting. An empirical approach was used to evaluate a series of exploratory designs and to modify solutions on the basis of subjective reports by individuals occupying the seats.

A number of specific design problems were investigated with the following results:

(1) Seated body profiles of 20 male subjects indicate that there is no single, or general seat contour that will fit a random selection of users. This finding supports the need for developing seat designs from materials that conform to a wide variety of body types.

(2) Use of nylon net material for body support surfaces satisfies the conformability requirement.

(3) The problem of adequate lumbar support in a net seat was solved by the development of a convexly curved seam at the junction of seat pan and seat back.

(4) A frameless net seat was designed to be suspended by six points at the crew station.

(5) A foam-rubber leg separator was designed to provide and maintain comfortable leg separation at the leading edge of the net seat pan.

The design activity reported here suggests that human factors requirements of a seat for long term occupancy can be met by a nylon net seat. The seat can accommodate a variety of users. It is compact and satisfies engineering requirements for light-weight seating.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Andres I. Karstens

ANDRES I. KARSTENS
Colonel, USAF (MC)
Asst. Chief, Aero Medical Laboratory
Directorate of Laboratories

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

The purpose of this report is to describe a program of experimental design research on a general-purpose work seat that can be used for military vehicles or weapon systems in which weight and long term habitability are primary considerations.

A number of studies have treated the general problem of seating and the factors which effect a comfortable sitting experience. As a result of numerous investigations, a sizable body of pertinent information now exists on the important variables to be considered for successful seat design. Among the many factors known to be of considerable importance are 1) the function of the seat, 2) the range of body sizes of intended occupants, and 3) the length of time a seat may have to be occupied (1, 4, 6, 8, 9, 10). Related to these are factors such as 4) the physical dimensions of the seat, 5) the angular relation between seat pan and seat back, and 6) more general structural features such as contouring of support surfaces, cushioning, and the provision of arm rests and head rests (2, 5, 17, 18). All of the variables thus far mentioned have to do with the human factors considerations in seating. There are, in addition, engineering requirements which must be met.

With the development of high performance aircraft of advanced design, the problem of adequately seating the operator without penalizing vehicular performance becomes one of integrating human factors requirements for habitability with engineering requirements for compactness and minimum vehicular weight. The problem is more critical when considered with respect to manned exospheric vehicles projected for the near future. Here, (at least in vehicles of the immediate future), even more stringent engineering restrictions are imposed on the equipment which can be supplied for operator comfort and function. These restrictions are prescribed by over-all vehicular design, power plant limitations, and the need for guidance, recording, and reconnaissance equipment.

Manuscript released by the authors July 1958 for publication as a WADC Technical Report.

From the human factors standpoint, it is necessary that an operator be maintained in an alert state, free of excessive fatigue, for optimum efficiency. However, to remain efficient over extended flight assignments, he must be permitted relaxation and rest when appropriate or necessary. One solution to the weight and comfort problem in seating is to apply new materials to seat design. In this paper, some general design concepts are developed for the construction of a light-weight operator seat from nylon net. The advantages of such a seat over more conventional designs now in use include the following:

1. Weight: Since performance and top speed of an aircraft are related to over-all weight, it follows that improved performance results from decreased weight. If weight can be reduced in the cockpit without risking operator malfunction, this reduction of parasitic weight has a proportional influence upon aircraft performance (4). Even the lighter seats in current operational aircraft weigh in the neighborhood of 50 to 75 pounds[1], whereas the estimated weight of a net seat is somewhat less than 10 pounds (3). This saving seems great enough not to be overlooked.

2. Comfort: In the operation of military weapon systems, seating discomfort can have serious consequences for successful completion of missions. As the effects of inadequate seating become prominent, they claim attention by heightening

---

1 Some representative weights are as follows:

C-124 Crew Seat (Weber), including cushions:	50 lbs.
F-86D Upward Ejection Seat, without rails:	60 lbs.
B-47 Downward Ejection Seat, without rails:	75 lbs.

awareness of bodily sensations. Attempts are made to correct the situation by postural changes which are often ineffective. The general result is to distract attention from the task at hand. Normal duties are complicated by new factors and normal situational stresses are heightened. Current seats do not satisfy comfort requirements for long-term accommodation at the work station; they only approximate them (17). In conventional seat designs the following design problems still exist:

a) Occupant size: The range of body sizes of seated occupants is extremely broad, according to extensive anthropometric surveys (7, 8, 11, 16). Seat dimensions have to accommodate all these individuals (or at least 90 per cent of the range as in the current AF design objective). If the seat pan is too deep, the short individual will be affected adversely in the popliteal area (behind the knees); if the pan is tailored to accommodate the short person, a tall individual may find the pan too short to afford proper stability. Similar size considerations are involved in seat back dimensions and placement of head rests (17).

b) Contouring: Studies of seating emphasize the advantages of contoured support surfaces since greater areal contact is provided for the back and buttocks (2, 5, 10, 15). Moreover, body shapes differ from individual to individual and a universal contour to fit all individuals is lacking (See pages 10 and 11 of this report; also references 2, 9). In addition, contoured support surfaces do not permit much shifting of body position for purposes of relaxation.

c) Body Support: Tolerance for long term sitting is a function, in part, of the amount of localized discomfort that develops in the buttocks region and in the small of the back (17, 18). It has been suggested (2) that the most efficient support for the back can be provided by fitting the back rest to the lumbar hollow; yet individual differences in body profile do not permit the realization of this objective with the fixed structures of seat designs now in existence.

The advantages of a net seat may be contrasted to the shortcomings of conventional seating. Net materials are flexible and thus can conform to a variety of body types or sizes. In this sense, the problem of individual differences is, to a large extent, circumvented. The conformability of the net furnishes greater areal contact for the body - a feature that existing seats often lack. The same flexibility which permits contouring also assures that the contouring will follow shifts in body position. Finally, by suitable tailoring of the net, it may be possible to furnish shaped supports for the critical lumbar and buttocks regions.

The present application is not the first use of net material for supporting an operator at his work station. In one of the earliest applications, Hertzberg (6) fabricated a comfortable prone-position bed for pilots. Nylon net was stretched over contoured side rails and adjustments were incorporated for fitting the bed to individual subjects. Longitudinal contouring was achieved principally by the shape of the side rails. Transverse contouring was provided by varying the tension of the net.

In a more recent application, Dempsey and Duddy (3) designed a nylon net seat for a balloon gondola. Their primary purpose was to produce a light-weight seat that would minimize over-all vehicular weight while providing as much comfort as this primary consideration permitted.

Formal and informal reports stemming from the above applications indicate that nylon net materials can accommodate operators comfortably at their work stations for long periods of time. However, additional research is needed to formulate design principles to be used with such materials. The program of design research outlined in this paper represents one approach to the problem. The techniques of the industrial designer were supplemented by information on human characteristics supplied by anthropologists, physiologists, and psychologists. Although the work is exploratory, it is felt that the results justify the development of a nylon net seat which can then be evaluated both in the laboratory and in operational situations.

2. THE SEAT DESIGN PROGRAM

The development of design principles for a nylon net aircraft seat may be outlined in two parts. In the first stage of the program, body profiles were found for a number of subjects who differed in body type, height and weight. Based upon these results, a series of initial design approximations were examined and modified. The second part of the program continued design development until a satisfactory solution was achieved. Methods for suspending a net seat were also examined.

2.1 Subjects

Body profiles were found for 20 male subjects. All were drawn from a pool of Tufts University students who responded to a call to serve as subjects (for pay) in human factors studies. They were selected to represent a wide range of gross body sizes, viz., height and weight. In terms of the 1950 Anthropometric Survey (7) of USAF personnel, subjects ranged in height from the 5th to the 95th percentiles and in weight from the 2nd to the 93rd percentiles (cf. Table 1, page 33). During all testing the subjects wore standard Air Force underwear.

2.2 Apparatus

The Jegart Profile Delineator[1] was used during initial design phases. This apparatus, pictured in Figure 1 (page 7) consists of two heavy wire mesh screens placed side by side. The screens are made of expanded metal fastened to vertical frames 8 feet long by 6 feet high. The frames were braced and bolted to separator bars at their lower ends. Distance between the screens was 18 inches.

To determine body profiles for seated subjects, steel rods, 3/8 inches in diameter, were pushed through corresponding mesh openings in each screen. Locations of individual rods were measured in terms of rectilinear coordinates. Steel tapes, fastened to the top of each frame, gave horizontal locations. Vertical distances of the rods from a reference point were determined by a steel tape fastened to the edge of a moveable T-square hanging vertically from the top edge of the apparatus. In operation, a rod position was located by sliding the T-square to a predetermined setting on the horizontal scale. The vertical dimension was then read from the T-square scale.

A wooden footrest, adjustable fore and aft, was constructed and added to the delineator. It was used to insure proper weight distribution for a seated subject as well as to simulate the rudder pedals and seating configuration for aircraft pilot seats. It was mounted on rods placed in the screens.

2.3 Net Material

Experimental seat surfaces were designed and fabricated from a special nylon fabric having strength characteristics of about 3,400 pounds per square foot (6). The material, technically a crocheted lace, is woven in the form of netting with a mesh of approximately 1/4 inch.

---

1 Supplied by the Crew Station Habitability Section, Aero-Med. Lab., WADC.

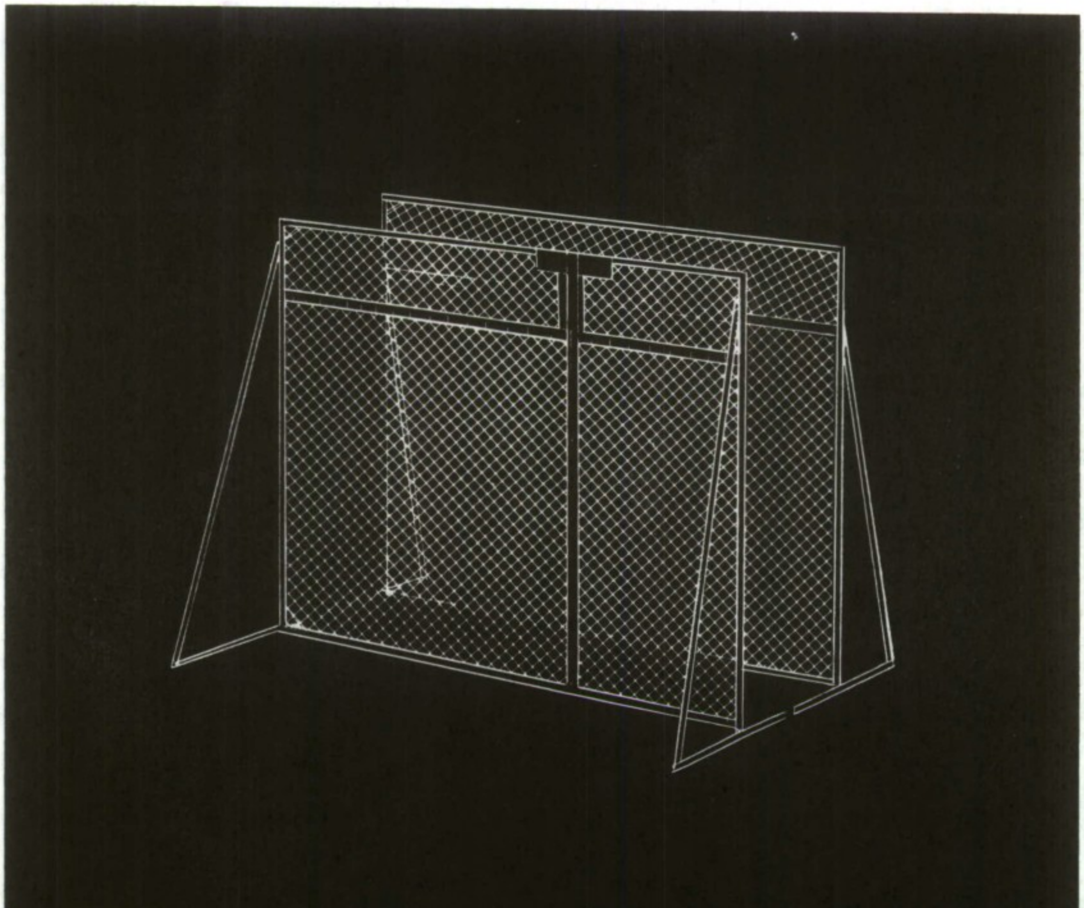


FIGURE 1 JEGART PROFILE DELINEATOR

3. INITIAL DESIGN DEVELOPMENT

3.1 Study 1: Delineation of Body Profiles

Purpose: To examine the range and variation of body profiles for a number of subjects who vary in stature and weight, and to determine whether a general profile can be found to represent all individuals.

Procedure: The following procedures were used to establish body profiles.

1. A standard "seat" of metal rods was set up in the apparatus as a control, or basic profile. Rods were inserted at appropriate mesh openings to form a flat 6° pan and a flat 13° back (included angle = 97°). All subjects started out with this initial seating configuration.

2. The footrest was then adjusted so that it was comfortable for the subject and afforded maximum upper leg contact with the seat pan without creating unusual pressures in the popliteal areas.

3. Beginning with the rods bearing the most weight, i.e., those under the tuberosities, the rods of the seat pan were then moved, one at a time, and refitted as closely as possible to follow the subject's buttocks profile. The aim of this fitting procedure was to position the rods so that the entire system gave the feeling of a comfortable seat surface. To aid the adjustment, subjects were asked the following:

> "Where is the seat uncomfortable?"
> "Does it press anywhere?"
> "Are any of the rods annoying?"
> "Is that better?" (after adjusting)

4. The rods forming the seat back were then adjusted to conform to the back profile of the seated subject.

5. The subject left the seat for a brief rest period. Upon return to the seat, his seated profile was again appraised and final adjustments were made for comfort. Questions similar to those under Number 3 above were again asked.

6. The rectilinear coordinates of the rods were recorded for the final profile.

Results: Figure 2 (page 10) shows the profiles obtained for 20 subjects sitting on metal rods adjusted to furnish maximum seated comfort. The profiles are presented in order of increasing curvilinearity. From the figure, it is obvious that there were numerous variations in body profiles, particularly in the lumbar and buttocks regions. These are areas known to be critical for comfort (17). It is apparent that the variations, expressed here as the subjects' final preferences for curved back and seat surfaces, are extreme. In Figure 3, profiles have been regrouped according to body sizes to show that pronounced profile differences exist even within size categories.

Discussion: These results furnish empirical support for other studies (2, 8, 9) which suggest that there is no single, or general, seat contour that will fit a random selection of individuals. Although a number of studies have outlined seat dimensions that accommodate a wide range of body sizes, the problem of comfortable sitting is more complex; one also has to consider variable body profiles. Some people have body sizes that fall within acceptable ranges, but body profiles and postures so deviate that they are not accommodated by standard seats.

It is possible to select users of a seat by setting limits based upon body dimensions. That is, one can select users who fall between the 5th and 95th percentiles for height (7, 9). This is a very simple selection procedure that can be undertaken with minimum effort. The selection of seat users on the basis of body profiles is, however, another matter, and one which cannot be solved so readily. From these profiles one might assume that a unique seat configuration might be ideal for each individual. Obviously this is an impractical solution. An alternative would be to develop a seat capable of accommodating a large variety of body profiles. This has been undertaken in the series of studies to be described.

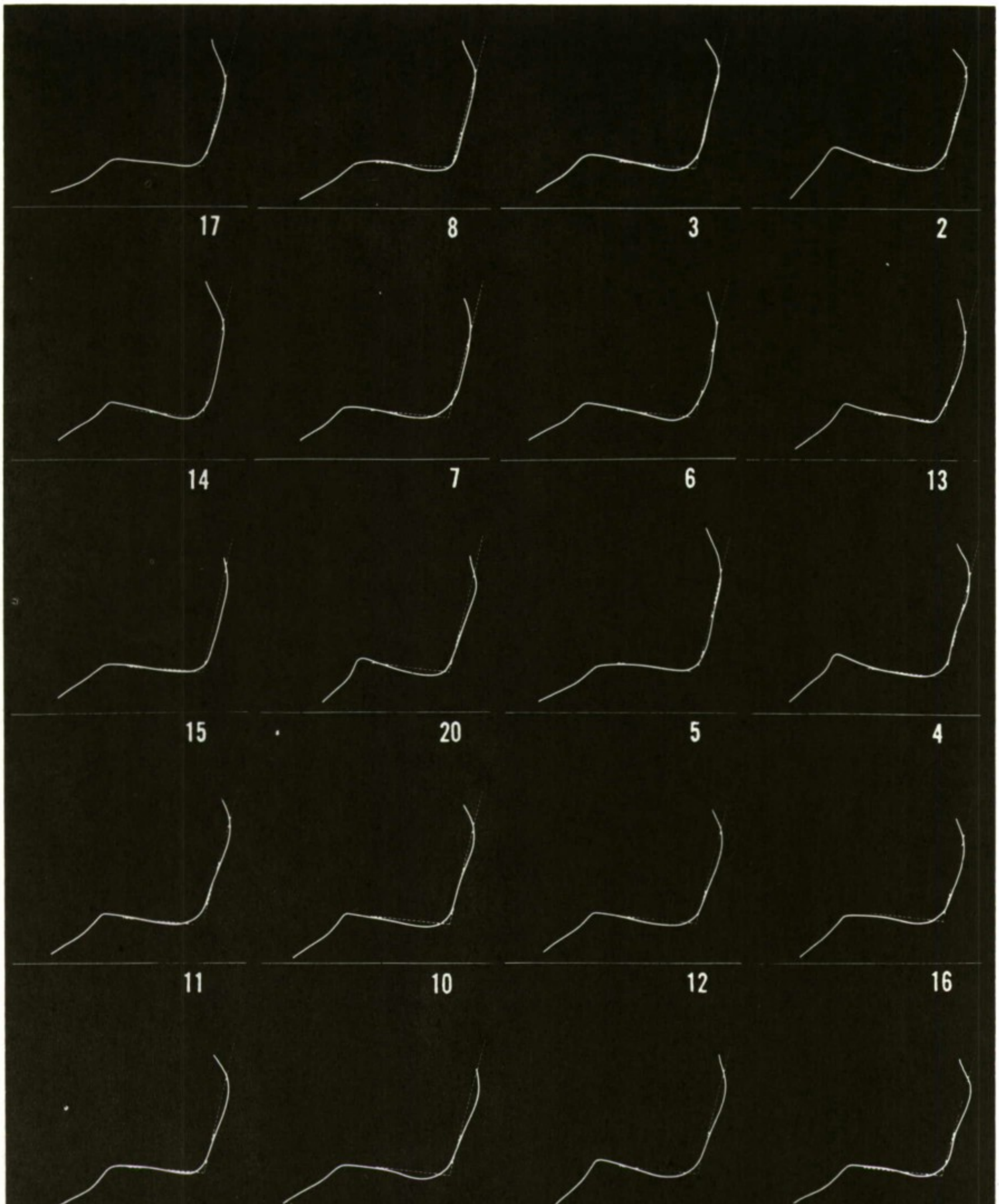


FIGURE 2 BODY PROFILES
in order of increasing curvilinearity

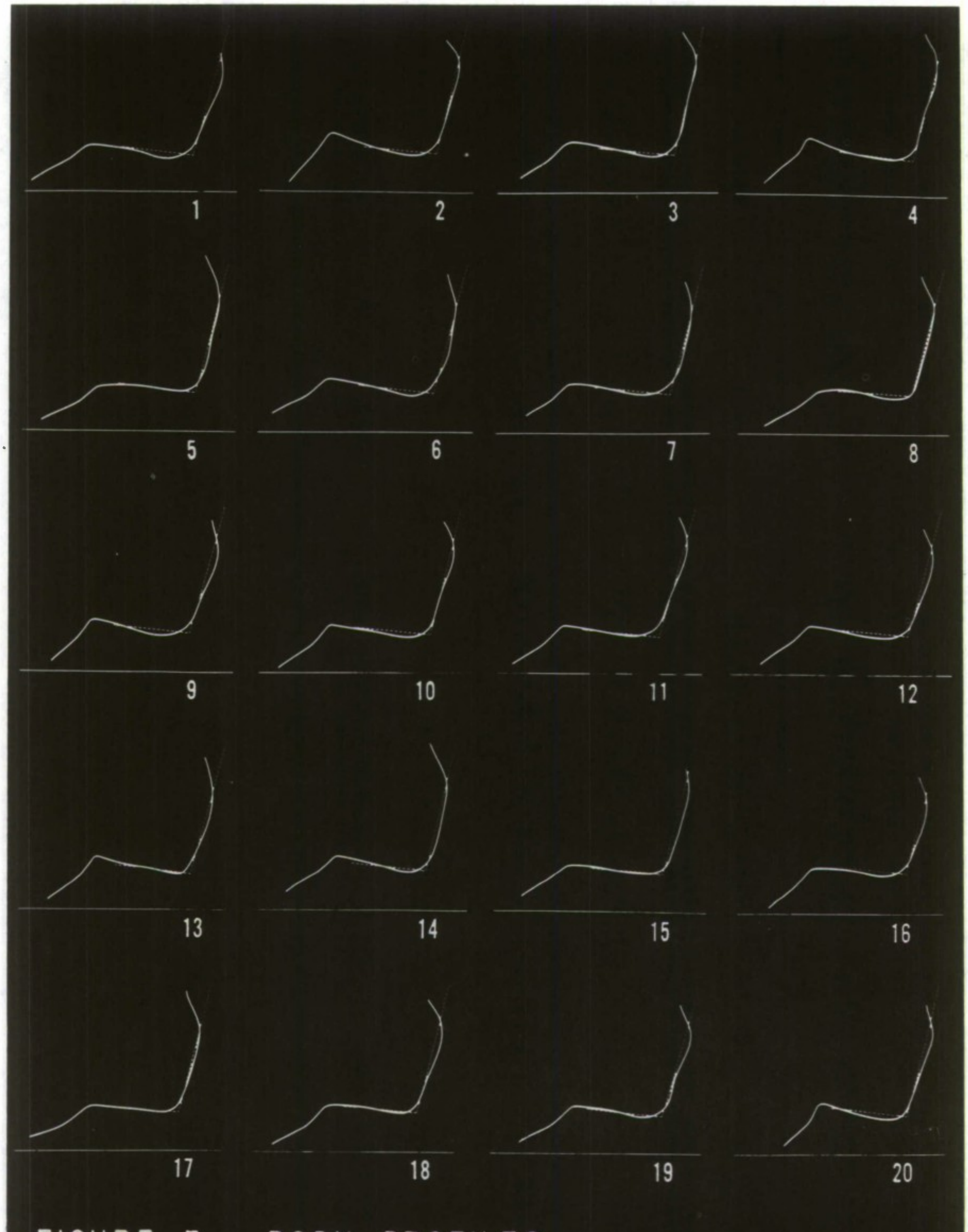


FIGURE 3 BODY PROFILES
in order of decreasing body size (c.f. table I, p. 33)

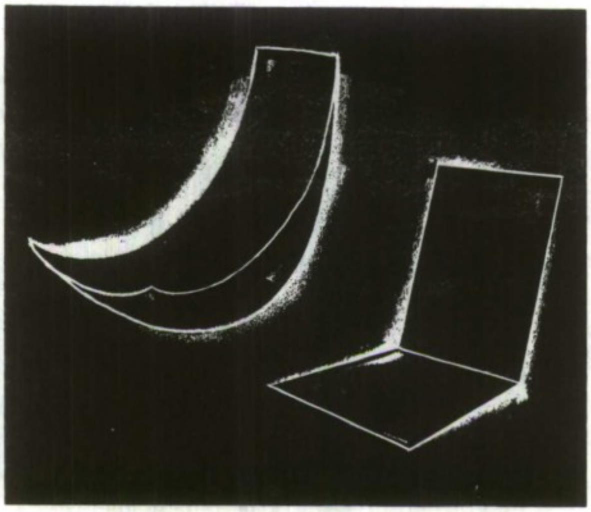
3.2 Study II: Application of Profile Results

Purpose: To examine contour-forming and stretch characteristics of nylon net applied in a preliminary seating configuration.

Procedure: Nylon net was suspended in the profile delineator. The net was stretched taut between the screens and fastened at two-inch intervals along each edge. All subjects began with the net initially mounted in a control configuration having a flat 6° seat pan and a flat 13° seat back.

After the subject had been positioned in the seat, the suspension points were systematically shifted to provide both lateral and longitudinal support. Subjects were then required to report when adjustments were satisfactory. The aim was to approximate, as closely as possible, the profiles that were found with the seat of metal rods. After the fitting phase subjects remained in the seating configuration for approximately 1/2 hour, during which time they reported on all aspects of the accommodation.

Results: Shifting of suspension points proved inadequate for profiling the net under load. Net characteristics were such that comfortable support was lacking in the critical lumbar and buttocks regions. With maximum tension on suspension points, the net still deformed beyond acceptable limits. Under load it tended to assume a sling (or hammock) shape (cf. sketches page 13). All similarity to a seat having well-defined seat back and seat pan surfaces was destroyed.



Comments, solicited from subjects who occupied the seating configuration, indicated a marked lack of lumbar support and a need for more adequate support for the shoulders and upper back. With this configuration, discomfort was evident at the end of the half hour sitting period.

Discussion: Examination of the net revealed that part of the difficulty with contouring and support was related to net deformation. When contoured bodies are supported by net, the load distributes unequally over contact areas and load lines are very evident. Individual mesh openings deform according to the direction of load forces. Most of the difficulty in achieving adequate net support can be related to this deformation; the stretch properties of nylon apparently play a relatively minor role.

The discomfort produced in this initial seating configuration also stemmed, in part, from the poor sitting posture imposed by action of the net under load. It will be recalled that the net deformed into a sling shape. Evaluations of hammock type seats (12, 13) indicate that lack of adequate lumbar support is a frequent criticism. When adequate support is absent, normal resting curvature of the spine is disturbed and the onset of fatigue is hastened (2, 13, 15).

The results of this initial experimentation with nylon net suggested that contouring and support cannot be based solely upon positioning of suspension points. It was next considered that a more successful solution might be found with net that is contoured prior to suspension. The hypotheses was examined by the next study in this series.

3.3 Study III: Examination of Net Seats with Built-In Contours

Purpose: To determine whether contour and support problems can be solved by partially contouring the net.

Procedure: An empirical approach was used. Hypotheses, generated by the previous study, suggested various ways of supporting the net to achieve suitable contouring. Some exploratory attempts were made to contour the net: (1) by shaping it with drawstrings attached to the screens of the apparatus; (2), by shaping 3/8" diameter rods to provide contour forming supports for the net; and, (3) by using nylon cord to "sew in" various experimental contours. Each design solution was carefully examined with the experimental seat under load; that is, a subject was positioned in the seat and drawstrings were adjusted to contour the net, or suspension points were shifted in relation to each other. As each new modification was incorporated, the subject commented on its adequacy. After adjustments were completed, the subject remained in the seating configuration for approximately one-half hour. During this time he was required to evaluate the accommodation of the seat. Because these configurations were exploratory, a long-term sitting evaluation was not attempted.

Results: The end product of this empirical approach to the design of flexible contoured seat surfaces was the development of a convexly curved seam at the intersection of the seat pan and seat back. A schematic diagram is shown in Figure 4 (page 15).

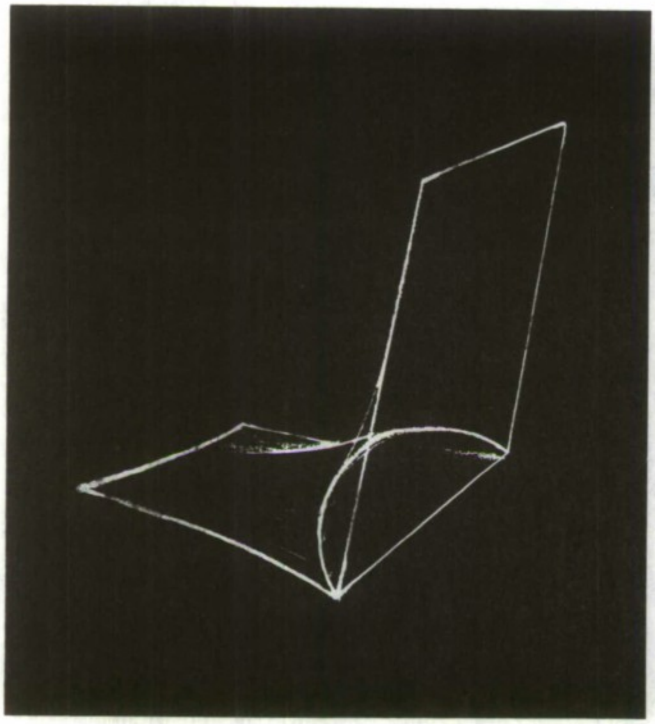


FIGURE 4

CURVED SEAM

to provide lumbar support in a net seat

The seam was sewn into the net with nylon parachute cord. The stages in the development of this solution may be briefly described by the following generalized results:

(1) Observation of the net under load indicated that bucketing was prominent in the buttocks and back regions. This result led to attempts to increase tension on the suspension points.

(2) Increased tension and action of the net under load did not contour the net to the lumbar hollow.

(3) A straight seam was sewn into the net to form an intersection of seat pan and seat back. Under load, lumbar support was still lacking. Therefore drawstrings were added to provide counter-pressure to pull the edges of the seat back from the body and to

increase tension in the center of the net. The action of the drawstrings generated a narrow band of pressure along the mid-line of the back and also increased convex (forward) contouring at the lumbar hollow. This provided beneficial support in the critical lumbar region and suggested that a curved seam might exploit this advantage and produce even better results.

(4) The straight seam was replaced by a convexly curved seam sewn into the net. Experimentation with seam dimensions showed the best curve to be one with a radius of 10 inches. A radius greater than this tended to push the subject out of the seat. A complaint frequently voiced by the subjects was: "I feel as though I am pitching forward out of the seat." On the other hand, a radius of curvature of less than 10 inches did not provide sufficient support in the lumbar hollow.

<u>Discussion</u>: Studies of seating comfort stress the need for proper lumbar support (1, 2, 9, 10, 15). These studies also recognize that people differ so much in body size and shape that the problem can be solved only by complicated seat designs, if at all (9). Fortunately, the results of this present study suggest that reasonably good lumbar support can be implemented in a net seat by a properly constructed seam at the junction of seat back and seat pan. In addition, the flexibility of net material permits it to conform to the different transverse contours of the human body. This is a second problem which has been recognized as important for seating comfort (2, 9).

Providing a curved seam in the net has other important advantages: The net no longer tends to assume a sling shape when occupied. The seam provides a convexity which produces support and comfortable pressure along the lumbar hollow. Due to the deformation properties of the net, the weight of a seated individual is sufficient to interact with the net and the curved seam so that downward pressure by the body is translated through the curved seam into a forward-acting pressure that supports the lumbar region.

3.4 General Summary: Initial Design Development

The design research in the first part of the net seat program, as reported here, served:

(1) To define the problems involved in the design of a net seat.

(2) To aid in the formation of a design based upon exploiting the characteristics of nylon net for the solution of these problems.

(3) To lead to design experimentation with possible solutions for further development of a net seat.

Contouring of seats is predicated on the assumption that maximum contact and support over the greatest body area leads to improvements in seating comfort (2, 18). With a fixed, or rigid contour this is successful for only one body position. If the seated individual shifts his position, the contouring no longer fits (2, 5, 9). With short-term sitting this may not be particularly serious. When the individual has to sit for long periods of time, however, it seems desirable to furnish a seat that will adjust to any body position to alleviate discomfort.

Netting is flexible, and flexibility of material suggests the property of omni-contouring. This means that sitting surfaces fabricated from net can be expected to conform not only to individual differences in body size and type, but also to shifts in body position. Some important principles for net seat design thus emerge: A net seat probably should not be fully pre-contoured. Rather, it should be self-contouring in the sense that the weight and shifting of the seated individual is responsible for some of the contouring. In other words, the net seat is not, in the usual sense, a functional seat until it is occupied.

In considering the net seat as a man-product relation, the product is effective only in relation to its user; when occupied, it changes shape and conforms to the occupant. This self-adjusting aspect is due to the nature of the material and to the way in which it is transformed into a seat by proper fabrication and suspension.

4. PROPOSED SEAT DESIGN AND SUSPENSION METHODS

Introduction:

Among other requirements, a work seat should be sufficiently compact to allow the operator a certain degree of unhampered movement (2, 10, 12). This means that structure and framing should be minimized wherever possible. In the crew stations of modern military aircraft, space is at a premium and equipment must often be placed around the operator more from necessity than for convenience. Although compactness is desirable, stability of the operator should not be compromised since unstable work platforms for the body require increased energy expenditures to combat the defect.

In this phase of the design program, various methods for suspending the net and stabilizing its occupant were examined to solve the problem of compactness and freedom from encumbering structure. Initial design experimentation led to the development of a curved seam which showed promise of conforming to a variety of body profiles. As the work progressed, there were increasing indications that a net seat, properly designed, would not require many suspension points.

Initially, the net had been fastened in the apparatus at two-inch intervals to establish a contour. The multiplicity of suspension points was used partly on the assumption that the net would need some sort of external framing. With the development of the curved seam between seat back and seat pan, however, most of the suspension points became inoperative and external framing seemed unnecessary. Attention then focused on better methods for suspending the net.

4.1 Study IV: Investigation of Suspension Methods

Purpose: To examine the feasibility of suspending a frameless net seat at a minimum number of points and to develop a net seat design which provides a stable body platform for the seated operator.

Apparatus: The basic net configuration of Study No. III was suspended in the profile delineator. Apparatus difficulties arose and new equipment was required for continued work. The Jegart Profile Delineator imposed restrictions upon experimentation and made work with the net difficult and time-consuming since the two vertical screens prevented ready access to the suspended net. The apparatus pictured in Figure 5 (page 21) was accordingly designed to solve the difficulty. It consists of standard Unistrut channels and fittings and serves as a three-dimensional suspension planner. This device permits quick and easy adjustability of all suspension points in three dimensions with a minimum of obstruction by apparatus during experimental work.

Procedure: The seating configuration with the curved seam was transferred to the three-dimensional planner and was suspended at six points. The net was attached to the apparatus by hooks at the top of the seat back, at the ends of the curved seam, and at the forward corners of the seat pan. During experimentation, the relative positions of the suspension points were systematically shifted to examine the effects upon seating accommodation. After all adjustments had been completed to the satisfaction of both the experimenter and the subject, attention was focused upon methods for improving seat stability. Items such as a lap belt and shoulder harness were added to the net and periodic reports were solicited from the subjects to guide subsequent design modifications.

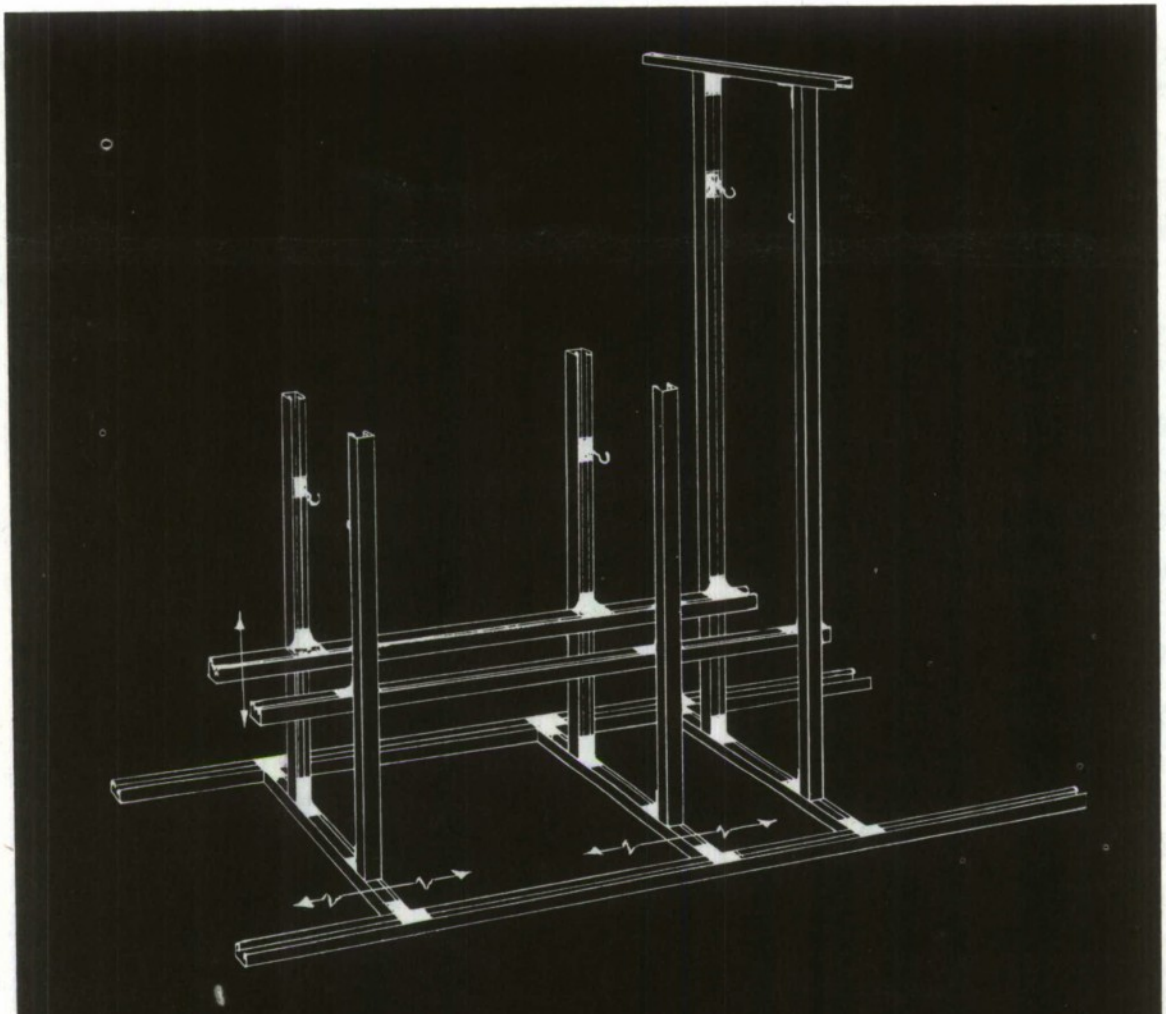


FIGURE 5
THREE DIMENSIONAL SUSPENSION PLANNER

Results: Examination of the new seating configuration indicated that certain additional design modifications were necessary. Although support in the lumbar and buttocks areas was not adversely affected, it was very evident that additional lateral support was needed. A common complaint was that the subject "didn't sit in the seat," i.e., his buttocks did not form a depression in the seat pan. An analogous sitting experience would be that of "sitting on" a flat bench-like surface as opposed to "sitting in" a bucket seat or an easy chair. To solve this problem of lateral support, and to provide the required restraining devices of an aircraft seat, additional netting was added to the sides and back of the seat to form a lap belt and shoulder harness. These drew the material of the seat snugly about the shoulders and buttocks. Subjects' reports indicated that the increased contact area furnished the necessary support in these regions.

Two additional design changes were needed for the seat pan. Subjects reported that their thighs were forced together by the sag of the net at the leading edge of the seat pan between the forward suspension points. A related complaint was that the resting weight of the legs placed the body in an uncomfortable attitude. Subjects felt as though they were pitching forward because rigid support was lacking under the knees.

With the frameless net seat, the leading edge of the seat pan sagged due to the resting weight of the legs. Attempts to solve the problem were aimed toward two objectives: (1), to provide adequate support under the knees for comfort and to prevent the body from "pitching forward," and, (2), to contour the leading edge of the seat pan for maintenance of leg separation.

Various design solutions were considered and discarded. A shaped metal rod was tried and discarded because it was too rigid and cut into the areas under the subject's thighs. Increasing the tension of the net at the leading edge of the seat pan and raising the forward suspension points also failed to solve the difficulty. A shaped leg separator was then fabricated from 1-inch thick foam rubber. The material was folded to double the cross-sectional area and to provide contouring at the top. The separator tapered in profile toward the rear of the seat pan and was flared out horizontally at its rear edges to blend into the seat. These details are illustrated in Figure 6 (page 23) which gives the dimensions and suspension points of the experimental mock-up.

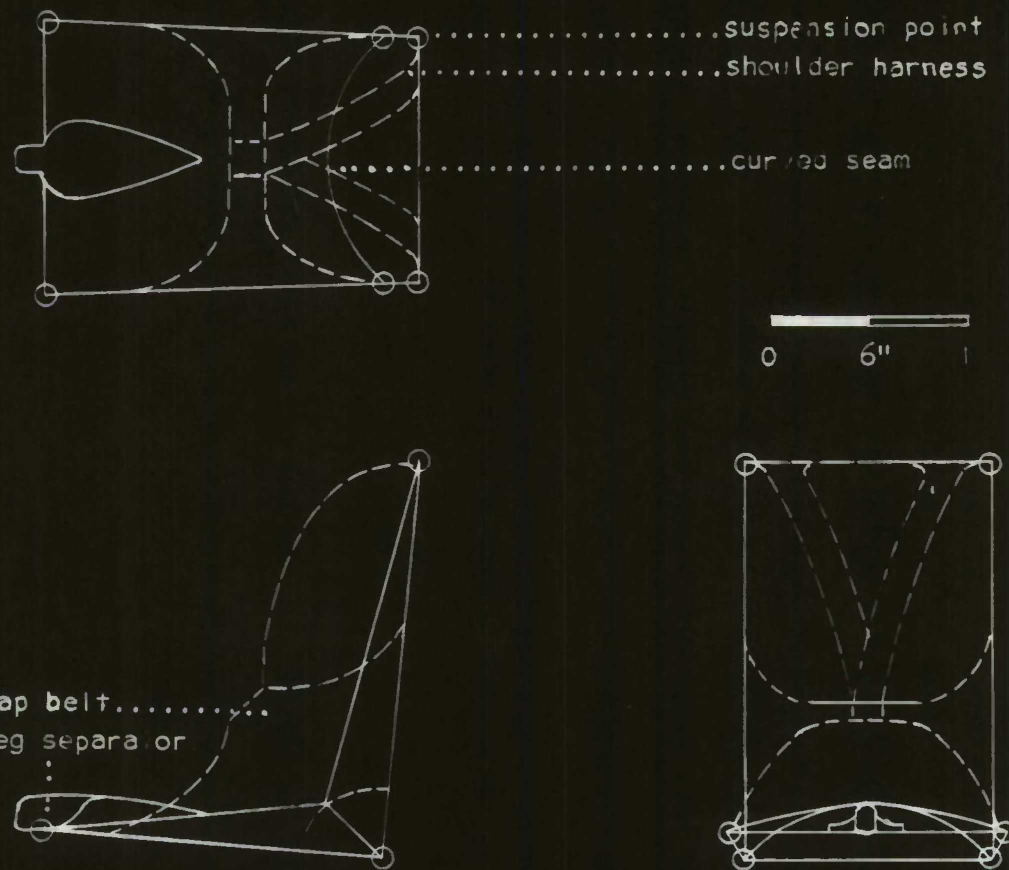


FIGURE 6 EXPERIMENTAL AIRCRAFT SEAT

- nylon net
- frameless
- omni-contouring
- integral lap belt & shoulder harness

Notes:

[1] Drawing illustrates seat before use. Seat pan and back contours vary to fit each occupant.

[2] Dashed lines indicate approximate position of lap belt and shoulder harness. These dimensions and curves will also vary as they contour to each individual.

For the mock-up, the separator was fitted into a pocket formed by the seat pan (which extended under the separator for firm support) and an auxiliary piece of net sewn over the foam rubber. The pocket served to hold the new component in place and to maintain its shape under load. Subjects' comments on the leg separator were favorable and indicated that it was satisfactory.

Discussion: The leading edge of the seat pan is a frequent source of difficulty in the design of hammock-type seats (3, 12, 13). Unless a frame of some sort is provided, an individual's thighs are forced together as resting weight of the legs causes the seat pan to sag.

Some seat designs solve the problem of leg separation by incorporating a tubular yoke over which net is draped (3). The yoke then acts to separate the legs and to shape the leading edge of the seat pan. There are disadvantages, however. The yoke assembly is a rigid structure which acts like a pommel and restricts freedom of movement in the seat. This introduces some of the disadvantages of a bucket-shaped seat (2, 10).

Other seat designs avoid the problem by using a transverse contoured frame at the leading edge of the seat pan. Since the frame is hard and often not padded, it is subject to the same criticisms which are directed at conventional seats that have poorly designed thigh pads (17). The rigidity of the seat pan edge also adds a fixed dimension that may not fit a wide range of potential users; i.e., the distance from the edge of the seat pan to the seat reference point can not be adjusted to fit the occupant, without an additional mechanical component.

These disadvantages are largely overcome by the present seating configuration since it is frameless and flexible.

Because the popliteal area (behind the knees) is a relatively sensitive body region, minimal support is indicated. The flexibility of the frameless net seat should therefore be ideal, if properly designed, to provide comfort and support for the thighs. The design problem is to provide minimal, but adequate, support without excessive contact and pressure under the knees. At the same time, attention should also be directed toward designing the seat pan so that it can shape itself (i.e., "give") under the knees with shifts in position, while at the same time maintaining comfortable separation of the legs at all times. Favorable comments of subjects who tested the foam separator indicate that these problems were solved satisfactorily.

4.2 General Summary: Proposed Seat Design

Aircraft seats have always been an integral part of the crew station. In one sense, the seat has also served as a component of the pilot's personal flight gear, since it is important for maintaining his comfort and efficiency at the work station. The design of a work seat of flexible net which forms itself about the user's body suggests that the seat may ultimately bear a more intimate relation to its occupant.

One of the unique by-products which resulted from the net seat program was the concept of a seat that could be "worn" by its user. As with other flight gear, it would be donned by a pilot, fastened to his body by shoulder straps and lap belt, and worn out to the aircraft to be fastened to appropriate fittings in the cockpit or capsule.

The program outlined in this report was primarily one of exploring seat designs rather than the fabrication and final development of a seat. Therefore, the specific design ideas presented should be viewed as recommendations and not necessarily as final answers. At the same time, it is felt that the solutions which were presented for various design problems should lead to a workable seat. The favorable comments by experimental subjects suggest that the seat shows promise of being ideally suited to maintain a wide range of potential users in a comfortable working position for long periods of time. It is therefore recommended that a prototype seat be fabricated and evaluated for long-term accommodation both in the laboratory and under actual flight conditions.

The final form of the nylon net aircraft seat is shown in Figures 7 and 8 (pages 27 and 28). In Figure 7, the seat is shown in outline form before suspension in the cockpit. Figure 8 is a sketch of the seat to show how it would appear in use.

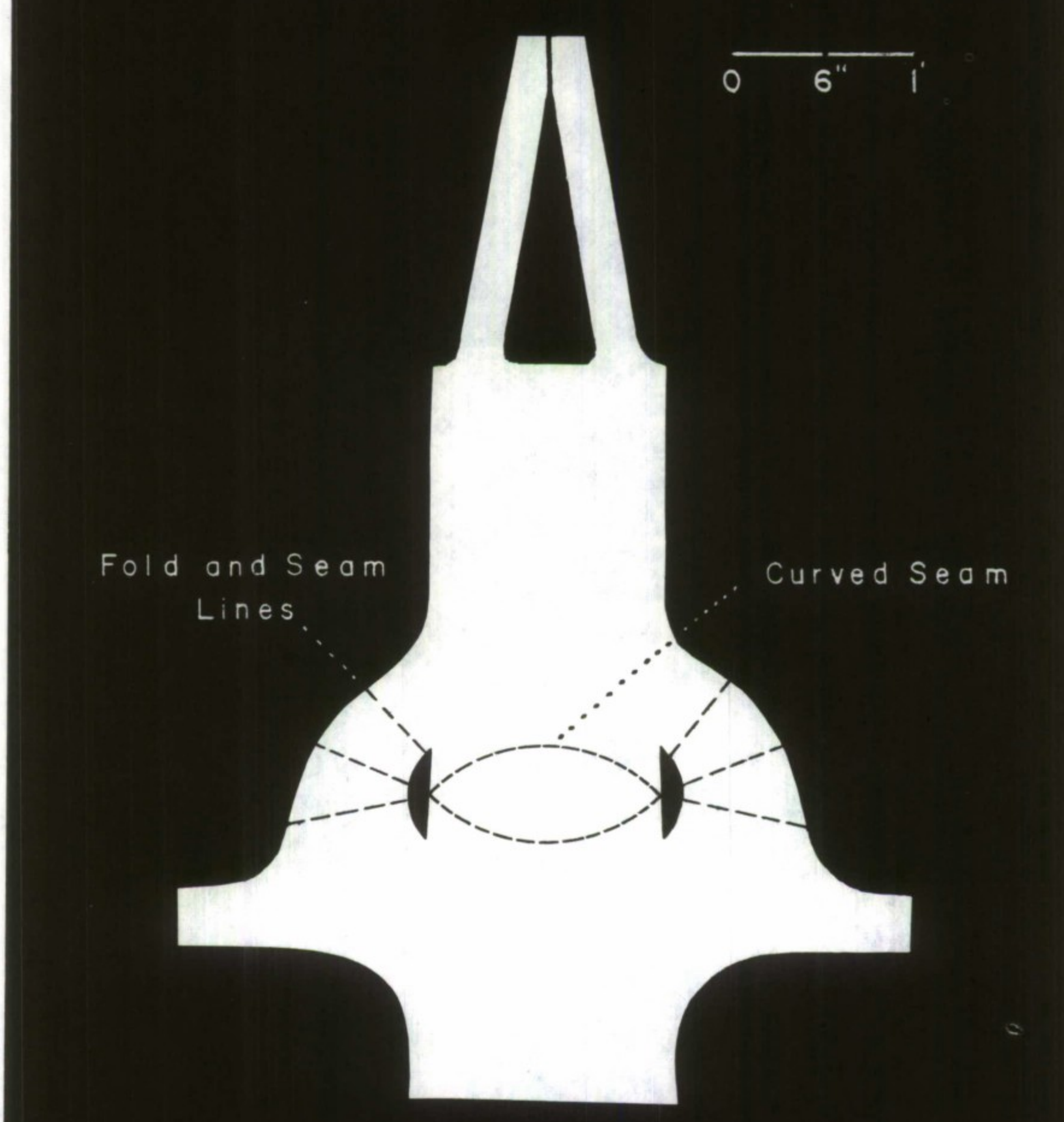


FIGURE 7 PATTERN FOR NET SEAT

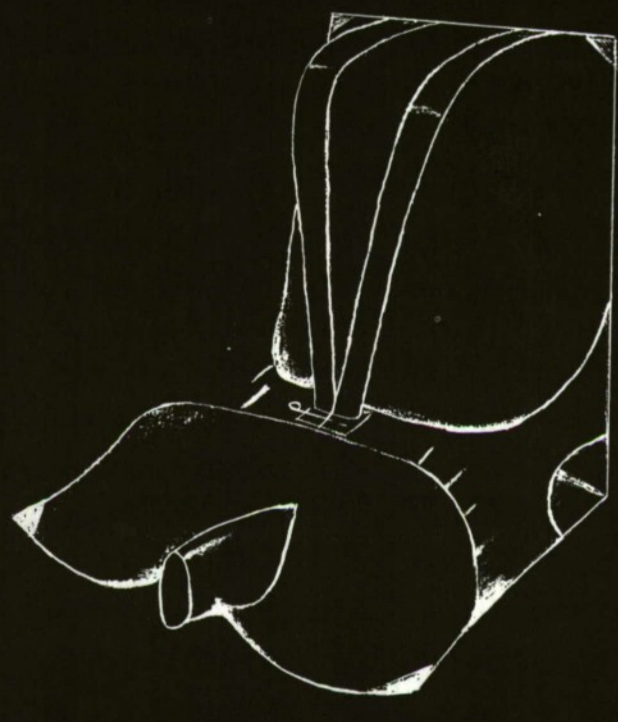


FIGURE 8 EXPERIMENTAL NET SEAT

5. BIBLIOGRAPHY

1. Baumunk, D.B., and Walpole, H.L. An Investigation of Seat Design for Combat Aircraft. Report No. ES 6950, Douglas Aircraft Co., Inc., Santa Monica, Calif., Nov., 1945.

2. Darcus, H.D. Seating in Relation to Anatomical and Physiological Principles. Report No. R.N.P. 46/326, Medical Research Council, Royal Naval Personnel Research Committee, England, Oct., 1946.

3. Duddy, John H., and Dempsey, Charles A. Light Weight Seating: Design Research and Development of a Net Seat for Project MANHIGH. Technical Report No. 58-307, WADC, Wright-Patterson Air Force Base, Ohio, October, 1958

4. Gagge, A.P. Human Factors in Aircraft Design. Memo Report No. TSEAL-3-695-53, Army Air Forces, HQ, Air Tech. Serv. Comm., May, 1945.

5. Henry, J.P. A Method for Assessment of Seat "Comfort" with a Description of Some Results Obtained with the Pilot's Seat of the Douglas BT2D Bomber. CAM Report No. 489, Naval Research Center, Div. Med. Sciences, Dec., 1945.

6. Hertzberg, H.T.E., and Colgan, J.W. A Prone Position Bed for Pilots. Report No. MCREXD-695-71-D, USAF Air Material Command, June, 1948.

7. Hertzberg, H.T.E., Daniels, G.S., and Churchill, E. Anthropometry of Flying Personnel - 1950. Technical Report No. 52-321, WADC, Wright-Patterson Air Force Base, Ohio, Sept., 1954.

8. Hooton, E.A. A Survey of Seating. Prepared for the Heywood-Wakefield Co., Harvard University, Boston, 1945.

9. Lippert, S. Designing for Comfort in Aircraft Seats. Douglas Aircraft Co., Inc., Santa Monica, Calif., July, 1949.

10. McFarland, R.A., Damon, A., Stoudt, H.W., and Moseley, A.L., Dunlap, J.W., and Hall, W.A. Human Body Size and Capabilities in the Design and Operation of Vehicular Equipment. Harvard School of Public Health, Boston, 1953.

11. Morant, G.M. "Body Measurements in Relation to Work Spaces in Aircraft." Anthropometry and Human Engineering. Buttersworths, London, 1955.

12. Naiman, J. Flight Testing a Hammock Seat. Memo Report No. TSCEP5ER-1888, Army Air Forces, HQ, Air Tech. Serv. Comm., May, 1945.

13. Patt, D.I. Comfort Evaluation of the Hammock-Type Fighter Seat. Technical Report No. TSEAL3-695-32EEE, ATSC, Wright-Patterson Air Force Base, Ohio, July, 1945.

14. Patt, D.I. Principles of Cockpit Seating. Technical Report No. TSEAA 695-58C, ATSC, Wright-Patterson Air Force Base, Ohio, February, 1946.

15. Randall, F.E. "Seat Comfort." Mechanical Engineering, 1946, 3, 1-3.

16. Randall, F.E., Damon, A., Benton, R.S., and Patt, D.I. Human Body Size in Military Aircraft and Personal Equipment. AAFTR No. 5501, AMC, Wright-Patterson Air Force Base, Ohio, June, 1946.

17. Slechta, R.F., Wade, E.A., Carter, W.K., and Forrest, J. Comparative Evaluation of Aircraft Seating Accommodation. Technical Report No. 57-136, WADC, Wright-Patterson Air Force Base, Ohio, May, 1957.

18. Slechta, Robert F., and Wade, Edward A. Comparative Evaluation of Aircraft Seat Cushions. Technical Report No. 58-311, WADC, Wright-Patterson Air Force Base, Ohio, in press.

6. APPENDIX I

A NOTE ON SOME DESIGN PROBLEMS ASSOCIATED WITH AN INTEGRATED NET SHOULDER HARNESS

The extension and shaping of net material to form the lap belt and shoulder harness as integral parts of the seat appear to be desirable design features. These items serve to stabilize the seat occupant and also give him the necessary lateral contact area and contoured support for maintenance of comfort in the buttocks region. The lap belt brings the sides of the seat pan up around the buttocks and upper thighs, shaping the pan in the process and providing more contact area for the body. However, certain problems appear when the shoulder harness is made an integral part of the seat back.

The shoulder harness is conceived as tapered net straps that are extensions of the seat back. These straps drape over the shoulders and are buckled to the lap belt. When the seat occupant is secured in this manner, problems of mobility are encountered.

Normally shoulder harnesses are separate items and usually not part of the seat. They function on an inertia reel which permits shoulder mobility during routine flying activities. During takeoffs and landings, or in emergency situations where crash is impending or when escape is indicated, the inertia reel locks the pilot's shoulders against the seat back. Similar provision has to be made with the net seat. When the shoulder straps are a part of the seat back, mobility is impossible. To solve the problem of mobility requires an engineering effort beyond the scope of the project reported in this paper. However, a design solution can be offered. It is suggested that the shoulder straps be retained as an integral part of the seat back but that suspension points at the top edge of the seat back be carried on sliding plungers (or carriages) which would permit a pilot to lean forward carrying his seat back along with him. During normal periods when the pilot performs routine duties, the entire seat back together with associated suspension points would "follow" every body movement. During emergency situations, the seat back with integrated harness would be drawn back and locked into position. This solution, similar to the inertia reel, is in keeping with a design objective of minimizing external framing for the seat.

7. APPENDIX II. SUBJECTS' HEIGHTS AND WEIGHTS

Table I

Subjects' Heights and Weights[1]

Profile Number	Subject	Stature Ins.	Stature Percentile	Weight Lbs.	Weight Percentile
1.	W.P.	76	99	195	93
2.	J.R.	76	99	190	88
3.	R.H.W.	75.3	99	200	95
4.	W.B.	74.5	98	185	84
5.	B.H.	74.5	98	175	74
6.	J.W.	74	98	160	46
7.	R.S.	72	88	180	79
8.	P.B.	71.5	85	170	65
9.	R.A.W.	71.5	85	165	56
10.	E.G.	71.3	82	175	74
11.	A.M.	71	79	160	46
12.	R.L.	70	64	148	24
13.	R.N.	69.5	56	175	74
14.	D.S.	69.5	56	160	46
15.	H.G.	67.7	28	142	15
16.	A.M.	67	19	175	74
17.	J.G.	67	19	130	4
18.	R.T.	66.5	14	160	46
19.	D.H.	66	10	135	7
20.	G.D.	65	5	125	2

---

[1] The percentiles given in this table are not based upon the present series of subjects, but are the nearest interpolations to the percentiles of the Air Force population as revealed in the Anthropometric Survey of 1950 (7).

AD- 209380

Tufts University, Bio-Mechanics Laboratory, Medford, Massachusetts.
LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON SEAT, by J. Forrest and E. A. Wade. December 1958. 33p. incl. illus. 18 refs. (Project 7222; Task 71747)
(WADC TR 58-309)
(Contract AF 33(616)-3068)
Unclassified report

This report describes a design research program for a light-weight aircraft seat made from nylon netting. An empirical approach was used to evaluate a series of exploratory

(over)

UNCLASSIFIED

1. Aircraft seats- Specifications

I. Forrest, J.
II. Wade, E. A.
III. Aero Medical Lab., Wright Air Development Center

UNCLASSIFIED

AD- 209380

designs and to modify solutions on the basis of subjective reports by individuals occupying the seats. A number of specific design problems were investigated with the results indicating that human factors requirements of a seat for long term occupancy can be met by a nylon net seat.

UNCLASSIFIED

UNCLASSIFIED

AD- 209380

Tufts University, Bio-Mechanics Laboratory, Medford, Massachusetts.
LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON SEAT, by J. Forrest and E. A. Wade. December 1958. 33p. incl. illus. 18 refs. (Project 7222; Task 71747)
(WADC TR 58-309)
(Contract AF 33(616)-3068)
Unclassified report

This report describes a design research program for a light-weight aircraft seat made from nylon netting. An empirical approach was used to evaluate a series of exploratory

(over)

UNCLASSIFIED

1. Aircraft seats- Specifications

I. Forrest, J.
II. Wade, E. A.
III. Aero Medical Lab., Wright Air Development Center

UNCLASSIFIED

AD- 209380

designs and to modify solutions on the basis of subjective reports by individuals occupying the seats. A number of specific design problems were investigated with the results indicating that human factors requirements of a seat for long term occupancy can be met by a nylon net seat.

UNCLASSIFIED

UNCLASSIFIED

AD- 209380

Tufts University, Bio-Mechanics Laboratory, Medford, Massachusetts.
LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON SEAT, by J. Forrest and E. A. Wade. December 1958. 33p. incl. illus. 18 refs. (Project 7222; Task 71747)
(WADC TR 58-309)
(Contract AF 33(616)-3068)
Unclassified report

This report describes a design research program for a light-weight aircraft seat made from nylon netting. An empirical approach was used to evaluate a series of exploratory

(over)

UNCLASSIFIED

1. Aircraft seats-Specifications

I. Forrest, J.
II. Wade, E. A.
III. Aero Medical Lab., Wright Air Development Center

UNCLASSIFIED

AD- 209380

Tufts University, Bio-Mechanics Laboratory, Medford, Massachusetts.
LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON SEAT, by J. Forrest and E. A. Wade. December 1958. 33p. incl. illus. 18 refs. (Project 7222; Task 71747)
(WADC TR 58-309)
(Contract AF 33(616)-3068)
Unclassified report

This report describes a design research program for a light-weight aircraft seat made from nylon netting. An empirical approach was used to evaluate a series of exploratory

(over)

UNCLASSIFIED

1. Aircraft seats-Specifications

I. Forrest, J.
II. Wade, E. A.
III. Aero Medical Lab., Wright Air Development Center

UNCLASSIFIED

AD- 209380

designs and to modify solutions on the basis of subjective reports by individuals occupying the seats. A number of specific design problems were investigated with the results indicating that human factors requirements of a seat for long term occupancy can be met by a nylon net seat.

UNCLASSIFIED

UNCLASSIFIED

AD- 209380

designs and to modify solutions on the basis of subjective reports by individuals occupying the seats. A number of specific design problems were investigated with the results indicating that human factors requirements of a seat for long term occupancy can be met by a nylon net seat.

UNCLASSIFIED

UNCLASSIFIED

AD- 209380

Tufts University, Bio-Mechanics Laboratory, Medford, Massachusetts.
LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON SEAT, by J. Forrest and E. A. Wade. December 1958. 33p. incl. illus. 18 refs. (Project 7222; Task 71747)
(WADC TR 58-309)
(Contract AF 33(616)-3068)
Unclassified report

This report describes a design research program for a light-weight aircraft seat made from nylon netting. An empirical approach was used to evaluate a series of exploratory

(over)

UNCLASSIFIED

1. Aircraft seats-Specifications

I. Forrest, J.
II. Wade, E. A.
III. Aero Medical Lab., Wright Air Development Center

UNCLASSIFIED

AD- 209380

Tufts University, Bio-Mechanics Laboratory, Medford, Massachusetts.
LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON SEAT, by J. Forrest and E. A. Wade. December 1958. 33p. incl. illus. 18 refs. (Project 7222; Task 71747)
(WADC TR 58-309)
(Contract AF 33(616)-3068)
Unclassified report

This report describes a design research program for a light-weight aircraft seat made from nylon netting. An empirical approach was used to evaluate a series of exploratory

(over)

UNCLASSIFIED

1. Aircraft seats-Specifications

I. Forrest, J.
II. Wade, E. A.
III. Aero Medical Lab., Wright Air Development Center

UNCLASSIFIED

AD- 209380

designs and to modify solutions on the basis of subjective reports by individuals occupying the seats. A number of specific design problems were investigated with the results indicating that human factors requirements of a seat for long term occupancy can be met by a nylon net seat.

UNCLASSIFIED

UNCLASSIFIED

AD- 209380

designs and to modify solutions on the basis of subjective reports by individuals occupying the seats. A number of specific design problems were investigated with the results indicating that human factors requirements of a seat for long term occupancy can be met by a nylon net seat.

UNCLASSIFIED

UNCLASSIFIED

AD- 209380

Tufts University, Bio-Mechanics Laboratory, Medford, Massachusetts.
LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON SEAT, by J. Forrest and E. A. Wade. December 1958. 33p. incl. illus. 18 refs. (Project 7222; Task 71747)
(WADC TR 58-309)
(Contract AF 33(616)-3068)
Unclassified report

This report describes a design research program for a light-weight aircraft seat made from nylon netting. An empirical approach was used to evaluate a series of exploratory

(over)

UNCLASSIFIED

1. Aircraft seats-Specifications

I. Forrest, J.
II. Wade, E. A.
III. Aero Medical Lab., Wright Air Development Center

UNCLASSIFIED

AD- 209380

Tufts University, Bio-Mechanics Laboratory, Medford, Massachusetts.
LIGHT-WEIGHT SEATING: DESIGN RESEARCH ON A NYLON SEAT, by J. Forrest and E. A. Wade. December 1958. 33p. incl. illus. 18 refs. (Project 7222; Task 71747)
(WADC TR 58-309)
(Contract AF 33(616)-3068)
Unclassified report

This report describes a design research program for a light-weight aircraft seat made from nylon netting. An empirical approach was used to evaluate a series of exploratory

(over)

UNCLASSIFIED

1. Aircraft seats-Specifications

I. Forrest, J.
II. Wade, E. A.
III. Aero Medical Lab., Wright Air Development Center

UNCLASSIFIED

AD- 209380

designs and to modify solutions on the basis of subjective reports by individuals occupying the seats. A number of specific design problems were investigated with the results indicating that human factors requirements of a seat for long term occupancy can be met by a nylon net seat.

UNCLASSIFIED

UNCLASSIFIED

AD- 209380

designs and to modify solutions on the basis of subjective reports by individuals occupying the seats. A number of specific design problems were investigated with the results indicating that human factors requirements of a seat for long term occupancy can be met by a nylon net seat.

UNCLASSIFIED

UNCLASSIFIED